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TRIPLE INVARIANT OPTICAL PATTERN RECOGNITION USING CIRCULAR HARMONIC SYNTHETIC FILTERS

Yang Baotang Cheng Yu /615*

ABSTRACT

This article, on the foundation of circular harmonic filter algorithms, combines synthetic discrimination functions to put forward circular harmonic synthetic filters. It solves traditional problems of matched space filters with input target geometrical distortions. On synthetic filters, computer simulations and optical correlation experiments were carried out. Results clearly showed that circular harmonic synthetic filters possess relatively strong triple invariant optical pattern recognition capabilities.

Key words: optical pattern recognition, circular harmonic filter, synthetic discrimination function, circular harmonic synthetic filter

I. INTRODUCTION

Optical pattern recognition (OPR) is a new form of technological science which has been developed in the last twenty years. It possesses very important prospects for application in all such areas as advanced defense space guidance, robot vision, industrial automation monitoring, as well as processing of remote pattern sensing, and so on. Moreover, matched space filters (MSF) are key components in optical pattern recognition. However, traditional MSF only possesses translational invariability. It is very sensitive to such geometrical distortions as input target dimensions, rotation, and so on. Thus, it leads to correlation output peak strengths and

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

recognition rates fall, causing traditional MSF, in actual applications, to be limited. Yang [1] first put forward the optimum circular symmetrical filter (OCF), and Hsu [2] put forward the circular harmonic filter (CHF), solving rotational distortion problems. After that, Casasent [3] reported that the synthetic discrimination function algorithm, to a relatively large degree, overcame the drawback of severe correlator function drops when there was distortion between imputed and reference target patterns. However, using SDF, synthetic filter function still drops following increases in the numbers of sample patterns [4,5]. If the filter dynamic range is increased, noise becomes severe, and output signal to noise ratio (SNR) drops. This /616 article, on the foundation of the work described above, puts forward a type of circular harmonic synthetic filter in order to reach the use of a single space filter to realize, within classes, dimensional, rotational, and translational triple invariant OPR. The special characteristic of this type of filter is that it opts for the use of circular harmonic components (CHC) to be sample functions. Because of this, it is not necessary to consider input target rotational deformations. It is only necessary to select different dimensional sample functions. Thus, there is a very great reduction in sample numbers, causing filters to possess relatively good recognition capabilities and output SNR.

II. CIRCULAR HARMONIC SYNTHETIC FILTER ALGORITHMS

Circular harmonic synthetic filter algorithms are to select n different dimensional standard target patterns, and, using polar coordinates, represent them as $f_1(r, \theta)$、$f_2(r, \theta)$、$\cdots f_n(r, \theta)$. Circular harmonic expansions are done on them respectively. Then, the Kth target pattern can be represented as

$$f_K(r, \theta)=\sum_{m=-\infty}^{+\infty} f_K^{(m)}(r)\exp(jm\theta) \tag{1}$$

In the equation

$$f_K^{(m)}(r) = \frac{1}{2\pi}\int_0^{2\pi} f_K(r,\ \theta)\exp(-jm\theta)d\theta \tag{2}$$

$f_K^{(m)}(r)\exp(jm\theta)$ is then designated as the mth order CHC and represented using $f_K^{(m)}(r,\ \theta)$. Taking the same order CHC associated with n individual target patterns, linear composites are made, obtaining

$$h(r,\ \theta) = \sum_{K=1}^{n} a_K f_K^{(m)}(r)\exp(jm\theta) = \sum_{K=1}^{n} a_K f_K^{(m)}(r,\ \theta) \tag{3}$$

Advancing a step, selection is made of the same correlation peak SDF algorithm associated with type recognition within the class, that is, it is required, for a certain input target $f_L(r,\ \theta)$, at the correlation origin point, to satisfy

$$\begin{aligned} f_L(r,\ \theta)\bigstar h^*(r,\ \theta) &= \sum_{K=1}^{n} a_K^* \int_0^{+\infty}\int_0^{2\pi} f_L^{(m)}(r,\ \theta) f_K^{(m)*}(r,\ \theta) r\, dr\, d\theta \\ &= \sum_{K=1}^{n} a_K^* r_{LK} = 1 \end{aligned} \tag{4}$$

In the equation above, r_{LK} represents origin correlation points between the Lth individual and Kth individual sample functions. They are designated correlation matrix elements. For n individual sample functions associated with different dimensions, in all cases, it is possible to write out equations similar to (4). Using the matrix vector form of expression, one has

$$\mathbf{R}\boldsymbol{a} = \boldsymbol{u} = [\underbrace{1,\ \cdots,\ 1}_{n\,个}]^T \tag{5}$$

In the equation, R is an n x n order correlation matrix. The matrix elements are none other than r_{LK}. The various individual components associated with vector a are none other than weighted coefficients a^*_k, in equation (4). **u** is an n x 1 order unit vector. It gives rise to a limiting function on synthetic filter output. $h(r,\theta)$ satisfying equations (3) and (4) are nothing else than pulse response functions associated with circular harmonic synthetic filters. Doing Fourier transforms on them, conjugates are again selected, and one then obtains circular harmonic synthetic filter $H^*(u,v)$. Due to the fact that pulse responses

associated with this type of filter are linear composites of the same order CHC associated with different dimension target patterns, the result is that it still possesses CHF rotational and translational invariability.

In circular harmonic synthetic filter synthesis processes, attention needs to be paid to the two points below:

2.1 Extraction of Circular Harmonic Components

Standard target patterns associated with different dimensions require, at the same point, extraction of the same order CHC. Only then is it possible to guarantee, within synthetic dimensional ranges, that when different target patterns within the same class are inputed, relevant output origin strengths are maintained invariable and output surface coordinate origins lie on the same point. Determination of expansion centers should cause comparisons between CHC information contents extracted at the points in question and their various independent optimum point expansions for target patterns with different dimensions. The fewer the losses the better.

2.2 Requirements Associated with Sample Function Numbers

As far as applying circular harmonic synthetic filter /617 algorithms in order to discriminate inputed targets with changed dimensions is concerned, it is necessary to have a series of standard target patterns covering the whole range of pattern dimension changes. In order to avoid the target patterns selected being too similar and seeming superfluous, we made use of an estimation formula put forward by Leger and Lee [6]:

$$N = \frac{\log(b)}{\log\left(1 - \frac{1}{2LB}\right)} + 1 \tag{6}$$

In the formula, 2L represents target pattern dimensions in directions x and y in the space domain. B represents the highest pattern space frequencies associated with the u and v directions in the frequency domain. b is the ratio between minimum and maximum dimensional change factors. Because of this, in situations where synthetic dimensional ranges are already known, it is possible, on the basis of equation (6), to estimate the required sample function number N.

III. COMPUTER SIMULATION EXPERIMENTS

In order to demonstrate the feasibility of circular harmonic synthetic filter algorithms and test their discrimination capabilities, we, first of all, carried out computer simulation experiments on designed filters. Fig.1 is the simulation experiment flow chart. In the Fig., output CGH stands for the fact that, after producing circular harmonic synthetic filter H*(u,v) data, it is possible to apply computer controlled holographic technology to make the filters in question. The SNR and energy diffraction efficiencies θ_H calculated in the block diagram are based on correlation results. Calculations are done of the two main filter function parameters in order to quantitatively reflect the discrimination capabilities.

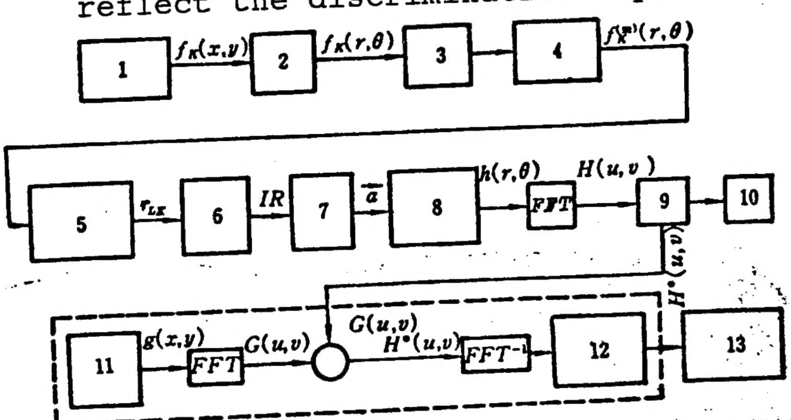

Fig. 1 Test procedure flow chart

1—Standard target input; 2—Coordinate conversion; 3—Extracting circular harmonic components; 4—Constituting the training set functions; 5—Calculating central correlation value; 6—Establishing correlation matrix; 7—Calculating the weighting coefficients; 8—Construction of impulse response of the filter; 9—Conjugate; 10—CGH writer; 11—Input targetimges; 12—Correlation output; 13—Calculating S/N and η_H

The standard target patterns selected for experiments are four two dimensional letters "F" with different dimensions. As shown in Fig.2(a), the dimensional ratios are 2.5:2.0:1.5:1.0. In order to raise filter discrimination performance, with the target patterns shown in Fig.2(a), we opted for the use of forms with strengthened edges, as shown in Fig.2(b). During experiments, respective extractions were done of the zero order and fourth order CHC associated with target patterns shown in Fig.2(b) making sample functions. Respective syntheses were made of zero order and fourth order circular harmonic synthetic filters.

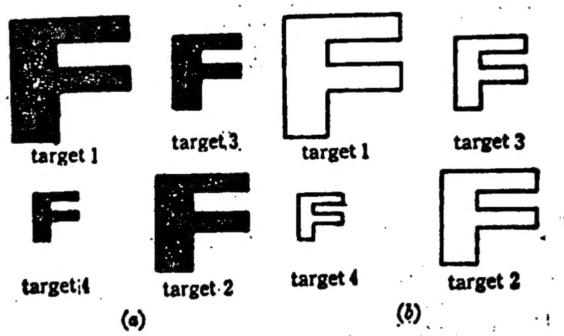

Fig. 2 Standard target input

Fig.3 and Fig.4 are simulation experiment results. It is possible to see that the two filters both possess relatively good correlation peaks. Moreover, fourth order circular harmonic synthetic filter output peaks are very sharp. This is advantageous to more accurate determinations of the positions of input targets. Fig.5 and Fig.6 are output peak strength change curves for filters when targets of different dimensions are inputed. The curves in question clearly show that, within covered filter dimension ranges (1 - 2.5), when target patterns are inputed, correlation peak strengths oscillate somewhat up and down at 1.0. Filters possess 100% accurate discrimination rates.

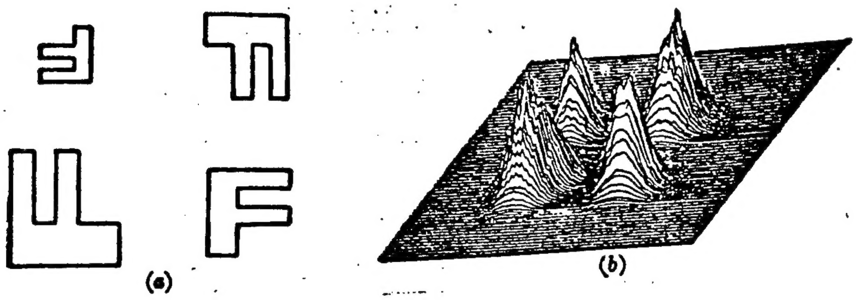

Fig. 3 Zero-order circular harmonic synthetic filter:
(a) input image; (b) three-dimensional plot of correlation output

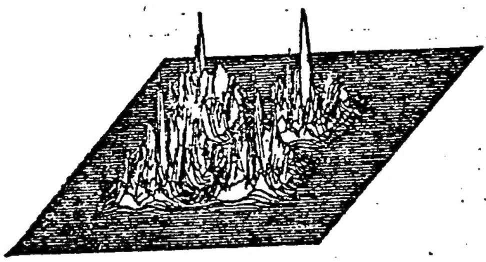

Fig. 4 Four-order circular harmonic synthetic filter's correlation output

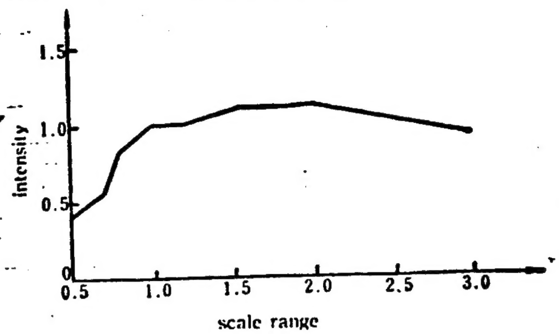

Fig. 5 Intensity of the correlation peak vs the scale change for the zero-order filter

Table 1 gives partial output SNR and η_H calculated results. In the table, the dimension ratios of target 5 and target 6 to target 4 are, respectively, 1.3:1.0 and 1.8:1.0. The formulae we opted for use in association with SNR [4] and η_H [7] are:

$$SNR = \frac{\text{maximum correlation peak value}}{\text{output surface average amplitude value}} \qquad (7)$$

$$\eta_H = \eta_m \frac{\iint_{-\infty}^{+\infty} |f(x, y) \star h^*(x, y)|^2 dx\, dy}{\iint_{-\infty}^{+\infty} |f(x, y)|^2 dx\, dy} \tag{8}$$

In the equations, f(x,y) is input target function. h(x,y) is filter pulse response function. η_m is recording medium diffraction efficiency. In calculations during these /619 experiments, this was selected at the ideal value of 1.

Thus far, computer simulation experiments have demonstrated circular harmonic synthetic filter filtering methods are completely feasible.

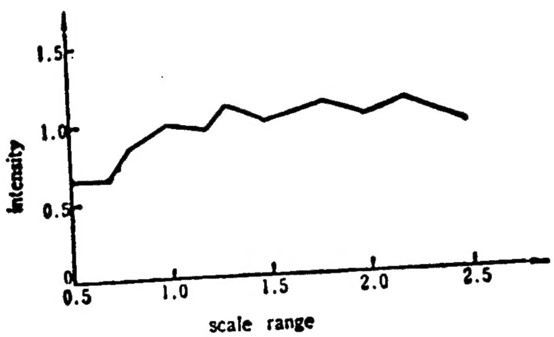

Fig. 6 Intensity of the correlation peak vs the scale change for the four-order filter

Table 1 Signal/noise and energy efficiency for zero-order and four-order filters

Input target		2	3	4	5	6
Zero-order filter	SNR	8.23	10.38	15.28	12.81	8.45
	$\eta_H(\%)$	10.1	9.9	8.2	9.6	10.3
Four-order filter	SNR	9.66	12.43	13.43	12.63	11.63
	$\eta_H(\%)$	8.8	8.6	14.1	10.6	8.7

IV. OPTICAL EXPERIMENTS

We opted for the use of circuitous phase encoding methods, respectively making two dimensional zero order and fourth order circular harmonic synthetic filters. We took the finished filters and put them into traditional optical correlation systems to carry out optical pattern recognition. Fig.7 and Fig.8 are optical experiment results. In the Fig.'s, what is clearly shown is that input target patterns are reproduced on relevant output surfaces. Experimental results clearly show that, within synthetic dimension ranges, locations on the relevant output surface corresponding to input target F's all have very well corresponding bright spots. Moreover, with regard to the

biggest target F's, which exceed synthetic dimension ranges, by contrast, the corresponding bright spots are relatively weak. This is in agreement with computer simulation experiment results. Filters show relatively weak triple invariant optical pattern discrimination capabilities.

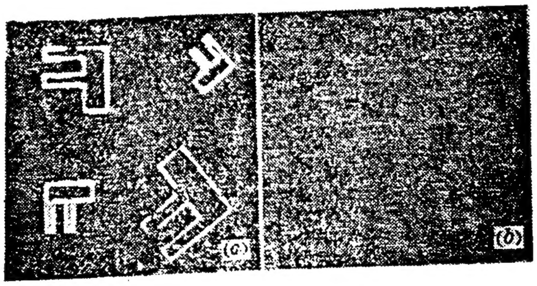

Fig. 7 Correlation output of the optical recognition system for the zero-order filter

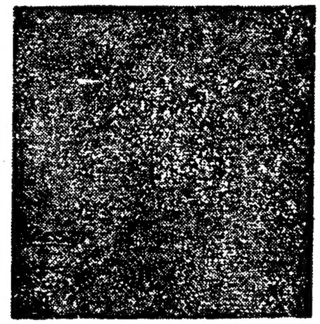

Fig. 8 Correlation output of the optical recognition system for the four-order filter

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